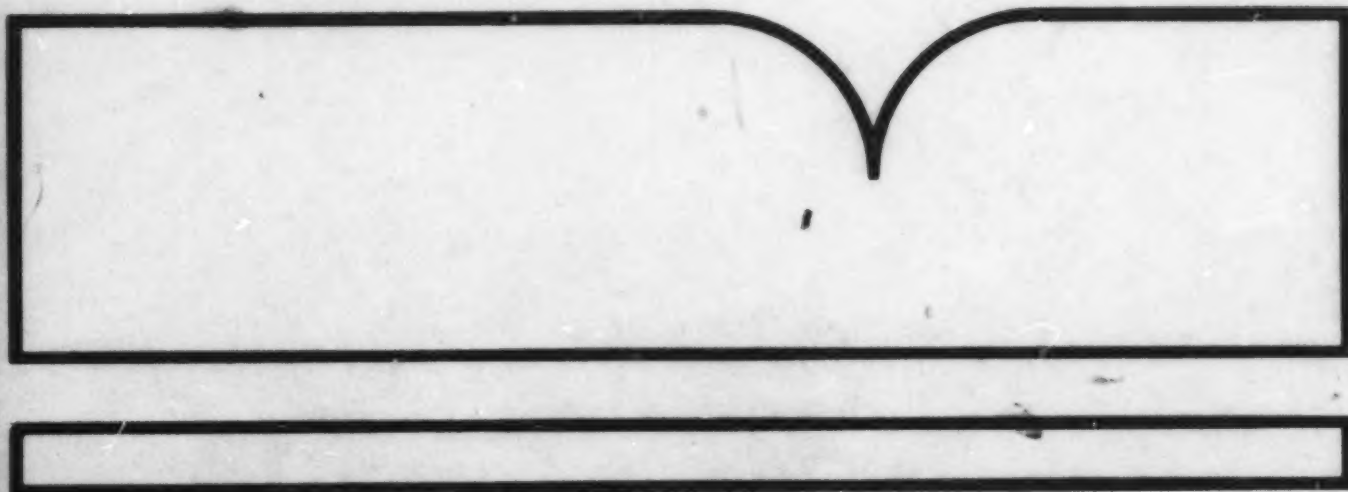


Covering Bottom Sediments as a
Lake Restoration Technique

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(KEY TERMS: eutrophication; water quality; lake restoration; sediment covering; fly ash; macrophyte control.)

INTRODUCTION

Eutrophication, a process in which lakes and reservoirs become excessively productive and shallow, is an increasingly serious nuisance to water users. Techniques to restore them after controlling nutrient and sediment income are the focus of an intensive international research effort (USEPA, 1979). The purpose of this paper is to review the status of one technique, sediment covering, for controlling macrophytes and sediment nutrient release.

Fly Ash

Fly ash consists of the small, airborne particles (size range 0.5μ to $> 100 \mu$) from coal combustion which are collected with electrostatic precipitators in electric power generating plants. It was apparently first suggested by Tenney and Echelberger (1970) that fly ash could be added to eutrophic lakes to remove phosphorus (P), to control P released from sediments, and to treat acid mine drainage.

The chemical composition of fly ash depends upon the type of coal used, and the type of collector (a typical range of composition is listed in Table 1). The properties of fly ash which make it a good agent for lake restoration are, according to Tenney and Echelberger (1970), its high absorptive capacity due to the large surface area per unit volume, precipitation of P due to water soluble lime and gypsum content, rapid settling, and cement-like characteristics which provide a seal over sediments. These properties may differ with the fly ash used (Yaksich, 1972).

TABLE 1. Typical Range of the Chemical Composition of Fly Ash From Pulverized Coal Fired Plants (from Tenney and Echelberger, 1970).

Constituent	Range, Weight-Percent
Silica, SiO ₂	34.00 - 48.0
Alumina, Al ₂ O ₃	17.00 - 31.0
Iron Oxide, Fe ₂ O ₃ or Fe ₃ O ₄	2.00 - 268.0
Calcium Oxide, CaO	1.00 - 10.0
Magnesium Oxide, MgO	0.50 - 2.0
Sulfur Trioxide, SO ₃	0.20 - 4.0
Loss on Ignition, Carbon	0.36 - 36.2

The P removal capacity of a fly ash varies with its lime and gypsum content. When some fly ashes are added to water, pH increases to 10-12 and the reaction at these pH values is the formation of CaPO₄, particularly on the surface of the particles (Yaksich, 1972). Up to 95 percent of the soluble reactive P is removed from experimental laboratory water columns with a dose of 10 g/l and this dose is effective in retarding P release from sediments for many days (Tenney and Echelberger, 1970). A 5 cm layer of fly ash will control P release under anaerobic conditions in the laboratory and is undisturbed by the release of gas bubbles. Thinner layers can be disrupted (Yaksich, 1972). The gas buildup under the fly ash when it is applied over macrophytes may become extensive enough to disrupt the covering, and a harvesting operation may be necessary before application (Theis and DePinto, 1976).

Despite an appearance as a potentially useful tool for lake restoration, based primarily on the laboratory studies of Tenney and Echelberger (1970) and particularly Yaksich (1972), many critical field and laboratory experiments to demonstrate effectiveness and environmental safety remain. The assertion by Tenney (1972) that the hazards of water contamination by fly ash applications are minimal has not been supported by subsequent research, and there is evidence to indicate that fly ashes applied to lakes or ponds for control of symptoms of eutrophication will themselves create more

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problems than they solve. Theis and DePinto (1976) list these possible adverse effects:

- 1) high pH,
- 2) dissolved oxygen depletion,
- 3) biological reduction of sulfate to sulfide,
- 4) heavy metal accumulation and toxicity, and
- 5) physical clogging and crushing of organisms.

These concerns stem in part from the report of Hampton (1972), who tested the effects of fly ash on laboratory populations of blue gill (*Lepomis macrochirus*), *Daphnia magna*, and chironomid larvae. The optimum dose (10 g/l) recommended by Yaksich (1972) was toxic to all groups. This dose was applied to a small fish pond over a three day period and all zooplankton and 99 percent of the bluegills and largemouth bass were killed. It is not clear whether high pH (10.9) or low dissolved oxygen were involved, but zooplankton returned after six weeks.

Fly ash has been shown to be toxic to fish, invertebrates, and algae. Cairns, *et al.* (1972), reported that after a spill of 130×10^6 gallons of a fly ash slurry into the Clinch River, all fish were killed over a reach of 100 miles (160 km), and there were drastic reductions in fish food organisms for 77 miles (123 km) downstream. High pH and a depression in dissolved oxygen were suggested to be the lethal factors. Recovery two years after the spill was not complete, but sufficient diversity and density of fish food organisms to support a sport fishery were present. Higgins, *et al.* (1976), found that algal assay cultures treated with 5 g/l fly ash and 150 g/l lime could not be restored to growth levels of controls by spikes with P or N, suggesting that the treatment either removed a growth factor or was inhibitory.

Heavy metal pollution of a lake has been considered to be one of the more significant adverse effects of a fly ash application. Theis and Wirth (1977) list the heavy metals, and their concentrations as a percent of total, found on the surface of particles of several types of fly ash (Table 2). Dreisen, *et al.* (1977), compared the heavy metal content of a fly ash disposal pond to a cooling lake without fly ash, and to the lake and pond outlets. The concentration of the most water extractable elements (B, F, Mo, Se) as well as As, were high in the pond and its outlet, but not in the lake inlet or outlet (Table 3). These elements could therefore also be found in lakes and ponds which have been treated with fly ash.

TABLE 2. Surface Concentration of Trace Metals on Fly Ash (expressed as percent of total; from Theis and Wirth, 1977).

Metal	Range	Av
Arsenic	65-100	93
Cadmium	<2-58	25
Chromium	15-84	44
Copper	25-75	48
Lead	5-40	8
Nickel	5-42	11
Zinc	10-70	30

TABLE 3. Concentration (ppb) of Elements in Samples From Water Intake (A), Cooling Lake Outlet (B), Fly Ash Pond Effluent (C), and Fly Ash Pond (D) (from Dreisen, *et al.*, 1977).

Element	A	B	C	D
As	2.6	7.0	27.0	33.0
B	100.0	950.0	12000.0	11000.0
Be	0.2	0.2	0.2	0.2
Cd	1.0	1.0	1.0	1.0
Cr	1.0	1.0	2.0	3.0
Cu	3.0	2.0	3.0	2.0
F	2200.0	3700.0	16000.0	ND
Mo	1.0	23.0	170.0	160.0
Se	1.0	1.0	57.0	60.0
V	2.0	60.0	130.0	140.0
Zn	590.0	350.0	440.0	580.0

Glass (1978), describing the work of Willard and his associates at the University of Wisconsin, reported that concentrations of Al, As, B, Cd, Cr, and Cu were elevated in a fly ash basin pond. He suggests that levels of these elements were sufficiently high to cause concern and further evaluation, supporting the view that fly ash addition to ponds and lakes could bring about concentrations of heavy metals toxic to aquatic life.

Gutenman, *et al.* (1976), studied the Se content of algae, macrophytes, an herbivore (tadpoles), and a detritivore (bull-head) in a pond adjacent to a land fill which received 450 metric tons/day of fly ash. The Se contents were twice that of a control pond, suggesting bio-magnification. The mercury content of fly ashes can be high, particularly with Pennsylvania, West Virginia, and Montana coals (Joensuu, 1971). The solubility of mercury at a pH above 9 (as would occur with a fly ash application) under reducing conditions (hypolimnion of a eutrophic lake) increases markedly, particularly with high sulfide concentration, leading to the formation of HgS_2^{2-} ions (Gavis and Ferguson, 1972). Experiments conducted by Theis and DePinto (1976) suggest that Hg may be released into the water column after a fly ash application.

Theis and Wirth (1977) point out that trace metals on the surface of fly ash particles will pose the most immediate threat to the biota. Many fly ashes, particularly those of western coal, bring about a sharp increase in pH of water. At elevated pH, Theis and Wirth (1977) and Thung, *et al.* (1979), found that metal desorption is slight, although Theis and Wirth's experiments indicate that arsenic desorbs readily at both high and low pH. At pH of 7 or below, desorption of metals was found by these authors to be high. Thus ashes which bring about lowered pH will be those of most immediate concern with regard to heavy metal toxicity (Theis and Wirth, 1977). But, even at a high pH metals do desorb from fly ash particle surfaces and could be expected to bring about accumulation in aquatic organisms.

A full scale lake application of fly ash was conducted in summer, 1975, when 1430 metric tons of fly ash (about 20 g/l) and 275 metric tons of lime were added to a section of Lake

Charles East, Indiana (Theis, *et al.*, 1979). This section had previously been isolated from the remainder of the lake by a barrier fastened to a highway bridge. The objective was to form a 4-5 cm layer on the sediment and to control P release.

Lake Charles is small (8.7 ha), shallow ($Z_{\max} = 3.0$ M, $\bar{Z} = 2.0$ M) and polymictic, with a moderate residence time ($T_w = 2.4$ years). It had received sewage effluent prior to treatment and was eutrophic. Diversion of 95 percent of P income was accomplished in 1974. The results of this study are difficult to interpret because the barrier between the two sides collapsed in winter, 1975, and because there are little biological and chemical monitoring data before treatment or for the untreated section.

The P concentration of the treated lake section fell to about 150 $\mu\text{g P/l}$, compared to a pretreatment concentration of about 225 $\mu\text{g P/l}$, but this decline may have been due largely to sewage diversion and flushing. Concentration remained at the 150 $\mu\text{g P/l}$ level through 1977 when monitoring ended. The application of fly ash to Lake Charles East may have controlled some P release from the oxygen free sediments, as suggested by laboratory studies of Theis, *et al.* (1979), but the continued high level of P in the water column two years after fly ash treatment suggests continued internal P loading and/or allochthonous P loading.

The heavy metal concentration in Lake Charles East water in 1976 was elevated for Fe, Mn, Cr, Zn, and Ni, but the lack of pretreatment data make this conclusion tentative, and the authors suggest that lake sediments were contaminated earlier by algicides and auto emissions.

There were biological effects from the Lake Charles East treatment. Thousands of small bluegills, but no bass, were killed, the oligochaete portion of the benthic fauna was nearly absent after treatment, and aestivating copepods were eliminated, as well as populations of Cladocera and Rotifera. The treatment changed the phytoplankton community from one almost continuously dominated by blue-greens to one dominated by flagellates, with a shorter blue-green bloom in the summer. The algae blooms were of reduced magnitude and water transparency increased. The biological community appeared to recover after the treatment, apparently by invasion from the untreated side. If the barrier had remained intact, simulating a whole pond or lake treatment, then redevelopment of the biota would have presumably been much slower.

Significant questions remain about fly ash as a sediment sealant, and there is a need for long term experiments to establish rate of release of heavy metals and extent of their bioaccumulation. The laboratory experiments of Tenney and Echelberger (1970), Yaksich (1972), and Theis, *et al.* (1979), have demonstrated the possible effectiveness of fly ash in P removal and in retarding some P release from sediments, but the application at Lake Charles East was equivocal due to failure of the barrier and the paucity of monitoring data, so that it remains to be seen if the possible advantages of fly ash exceed the short range and the potential long range detrimental effects. The reader is referred to Theis, *et al.* (1979), for additional details of the Lake Charles East study and for a

further review of fly ash as a lake restoration material. Further evaluation of Lake Charles East should be done.

At this time there is no evidence to support the public or private use of fly ash application as a eutrophic lake restoration technique.

Sheeting and Screening

Plastic sheeting has been suggested (e.g., Dunst, *et al.*, 1974; Peterson, *et al.*, 1974; Boyter and Wanielista, 1973) as a potentially effective technique to control macrophytes and nutrient release from sediments. Sand covered sheeting may also be useful in construction of swimming beaches. The published literature on the use of these materials is small and little is known about effectiveness, cost, or application techniques.

The properties of some of the common materials have been reviewed by Kumar and Jedlicka (1973). While some compounds have a specific gravity above 1.0, nearly all need to be anchored, and most also require perforation to prevent "ballooning" from gases released from the sediments. Varying thicknesses and materials have been employed but the most common is 0.1 mm (4 mil) black polyethylene, a material which is strong and impermeable.

Sheeting to Control Macrophytes

The largest scale reported experience with sheeting was the Marion Millpond, Wisconsin, Project, described by Born, *et al.* (1973); Peterson, *et al.*, (1974); and Nichols (1974).

Marion Millpond (44 ha), built in the 1850's, had become shallow, weed-choked, overpopulated with small panfish, and had winter oxygen depletions. The pond was drained and cleared of stumps and debris and ten hectares were eventually covered with 0.1 mm black polyethylene in an attempt to stop or retard macrophyte regrowth. The material was initially laid on the mud, anchored with rocks, and perforated. Then 7-15 cm of sand and gravel were placed over it. This application technique was slow and tedious due to soft sediments, and a simpler, more economic technique was sought. Water level was manipulated to allow water to just cover the area to be treated, the sheeting placed on snow cleared ice and weighted with sand-gravel, and then the water suddenly withdrawn to crack the ice and cover the pond bottom with sheeting. This application technique proved to be effective.

The pond was refilled in 1971, and in 1971-72 good control of macrophytes was achieved. By 1973, and in subsequent years, plants were able to root in the sand-gravel covering and nuisance growths returned (Nichols, 1974).

Born, *et al.* (1973), estimated the cost of sheeting (1970 prices) to be \$81/ha. Labor and other costs were donated by citizens of the area.

Nichols (1974) reported that gravel or plastic sheeting reduced the biomass of *Chara* in Windfall Lake, Wisconsin, to zero during the first year of treatment. Bluegill and bass spawning areas were provided by the sediment covering.

Another material was evaluated by Cooke and Gorman (1980). In March 1978 a finely porous compound, spun bonded DuPont Typar 3201 and 3202 black polypropylene

was applied to 116 m² of the exposed sediments of Country Lake, a small, weed-choked pond in Portage County, Ohio. The material was overlapped along 1 m wide strips, and anchored with cement blocks. Regrowth of macrophytes in 1978 was completely controlled and the sheeting was sufficiently permeable that "ballooning" did not occur. *Najas flexilis* developed a small biomass on the silt which settled on the sheeting, and some macroalgae appeared but were not a nuisance. Fish schooled in the open area and good fishing success was reported. Material cost (1978 price) was \$2600/ha. Application was tedious in the soft mud. However, the material sinks easily due to its high permeability to water and could be applied by wading, or by divers or swimmers before the spring bloom of macrophytes, or from a reel in a boat. Further evaluation of this material is needed.

Armour, *et al.* (1979), describe the effectiveness, costs, and difficulties with the use of five sheeting materials for the control of Eurasian water milfoil (*Myriophyllum spicatum* L.) in British Columbia. Their results are summarized below.

Black polyethylene was found to be effective in weed control for up to two years, and cost (including materials, labor, equipment rental, and overhead) was estimated to be \$12,558/hectare. Application was difficult due to buoyancy, and the sheeting could be easily dislodged by wave action. Also, application was difficult over uneven sediments, and the material tends to slide down steep inclines. As with the other non-permeable materials, gas escape holes were cut and weeds grew through these. Polyethylene degrades rapidly in sunlight. The environmental effects include creation of anoxic conditions below the sheeting and possible interruption of fish spawning. The material is not suitable for areas where boating activity could disrupt it.

Hypalon is a nonbuoyant synthetic rubber compound which is heavy and hard to handle. The material gave complete milfoil control, but gas accumulation under it occurred, even with gas escape holes. Weights were required to keep it from shifting. The material is inert to sunlight and does not rip. Per hectare cost was \$59,452. The material was recommended by Armour, *et al.* (1979), for application to localized areas.

Polyvinyl chloride is nonbuoyant and easier to handle than polyethylene. In trials, it kept a small area weed free, but like other sheeting compounds silt may accumulate on it and provide a substrate for plant development. Material costs were estimated at \$15,275 per hectare.

Polyethylene tarps were as effective as polyethylene, but more difficult to handle and four times as expensive.

Permealiner is a semipermeable black polypropylene material which allows some movement of water and gases across it. The material is buoyant and had to be weighted. Milfoil grew on the silt which accumulated, and fine roots penetrated the sheeting. Cost was estimated to be \$27,000/hectare.

Mayer (1978) evaluated polyvinyl chloride-coated (PVC) fiberglass screening ("Aquascreen") of three sizes - 9.9 apertures/cm², 39 apertures/cm², and 62 apertures/cm² - as a means of controlling rooted aquatic vegetation in Chauga Lake, New York. Screening was placed by SCUBA divers directly over *Myriophyllum spicatum* and *Potamogeton*

crispus beds, and anchored with metal T-bars. According to visual observations, the 39 and 62 aperture/cm² screens brought about complete decomposition of rooted plants in 2-3 weeks, with no dissolved oxygen depletion. The 9.9 aperture/cm² screen was much less effective. Screens of 39 apertures/cm² did not maintain high levels of control over a one-year period, except in waters greater than 1.8 M depth, where 60 percent control was maintained. Seed germinations and regrowth occurred on screens after significant sedimentation (2-3 years after deployment) had taken place, but autumnal removal of these screens followed by repositioning in spring seemed to correct the sedimentation problem. Cost of the 62 aperture/cm² (1979 prices) is \$140.00 for a roll 7 feet wide by 100 feet long (Menardi-Southern Corporation, Augusta, Georgia).

A further study of the 62 aperture/cm² fiberglass screen was conducted by Perkins, *et al.* (in review). Panels of screening were attached to the sediment in July in a shallow (0.5-2.0 meters) and a deep (2.0-3.0 meters) section of a Lake Washington bay. Panels were removed at the end of one, two, or three months to determine the relationship between coverage time and effectiveness of macrophyte (primarily *Myriophyllum spicatum*) control.

The water column was free of macrophytes for the duration of emplacement, and regrowth, even after one month of cover, was not great. Complete decomposition, in contrast to Mayer's observation, was not found, although *Najas flexilis*, *Potamogeton crispus*, *P. berchtoldii* var., and *P. richardsonii* were virtually eliminated after two and three months' coverage. Screens which were not anchored close to the sediment "ballooned," developed pockets after attempts to depress them with bricks, and supported growth of milfoil in the pockets. No adverse changes in dissolved oxygen and other water column characteristics were found.

Mayer (1978) suggested that control by the screens was due to light limitation. Perkins, *et al.* found light in excess of that needed by *Myriophyllum spicatum* beneath the screens, and only when screens were placed directly on growing plants was a significant reduction in biomass observed. They suggest that physical or space limitation is more important.

Mayhew and Runkel (1962) employed black polyethylene sheeting to block sunlight entering sections (180-300 m²) of ponds by applying the sheeting to the pond surface. The technique appeared to be successful against several species of *Potamogeton* if left in place for about three weeks, and against *Ceratophyllum demersum* if left in place for four weeks. Success against *Potamogeton* was particularly good if the area was covered before the plants reached maturity. Control of *Chara* was more difficult, requiring up to 60 days.

Sheeting to Construct Swimming Beaches

Born, *et al.* (1973), describe the use of polyethylene sheeting to construct a new swimming beach at Marion Millpond. Black 0.1 mm polyethylene was placed over the sediments after drawdown and covered with a thick sand layer. The sand was then spread to a 1:8 grade, creating a sandy lake bottom and a sloping beach. There has been no followup report, but

new sand would presumably be added to replace that which was washed away by waves. Nichols (1974) reported that a gravel-plastic sheeting application created a firmer bottom for a swimming beach in Winfall Lake, Wisconsin.

Sheeting to Retard Nutrient Release

Polyethylene sheeting (0.01 mm) is effective in retarding nutrient release in experimental laboratory water columns under deoxygenated conditions, for periods as long as the typical lake stratification (Hynes and Greib, 1967, 1970). Iron and nitrogen release were also controlled, and the authors suggest that small lakes could be improved by covering hypolimnetic sediments. There appears to be no published account of any such attempt. The technical difficulties would be large, the costs high, and feasible only for lakes with water level control.

The use of plastic sheeting for control of macrophytes and sediment nutrient release has received insufficient evaluation to make conclusions about effectiveness, duration, application problems, and costs. There have probably been many treatments of lakes and ponds with these materials but few have been described in the literature. The use of sand-gravel to anchor the sheeting is not entirely satisfactory because this material becomes conditioned by lake water and may support plant growth, particularly the shallow-rooted *Najas flexilis*. Spun-bonded polypropylene, a material which will permit escape of gases, may be more effective than polyethylene but is expensive and its effectiveness has not been well documented. The PVC-coated fiberglass screen appears to be a promising control method and is receiving additional evaluation.

Clay and Sand

Very little published information is available regarding the use of clays or sand to retard nutrient release or macrophyte growth. The unpublished work of Yaksich (1972) suggests that certain clays, but not sand, gravel, or silt, could be used to effectively seal lake sediments. In laboratory experiments under anaerobic conditions, a 5.0 cm layer of kaolinite and Tennessee clays was effective in retarding P release up to 140 days without disruption of the layer by gas formation. Thinner layers burst. Silt and sand were not effective. The settling velocity of clays was found to be good, except for Bentonite, but it could be necessary to add a precipitant (such as alum) to remove clay from the water column. Water circulation up to 10 cm/sec, after settling, did not disturb clay layers, but an aluminum hydroxide floc over clay was easily disrupted.

A full scale lake treatment with clay has not been reported, but Robbins and Nelson (1977, abstract seen only) applied clays to isolated columns in farm ponds and found that they did not effectively reduce productivity or limit nutrient availability.

The effectiveness of clays as a sediment sealant is largely unknown and should receive further study. Heavier materials such as sand are apparently ineffective because they sink into flocculent sediments.

SUMMARY

1. The amount of published information about clays is insufficient to draw conclusions about effectiveness, cost, or duration, but indications are that further evaluation may produce positive results. Additional study is recommended.

2. Plastic sheeting has received more attention and it appears that it could be effective in retarding macrophyte growth and nutrient release. There are problems with application methods and in anchoring the material. Sand-gravel anchors are themselves capable of supporting macrophyte growth. Spun-bonded polypropylene, which will not balloon from gas release and thus does not need extensive anchoring, could be a better material than polyethylene, but it will permit nutrient release. The cost of these materials is \$1500-2600/ha. One effective and less expensive technique may be to use them around docks, beaches, and boat mooring areas where application can be accomplished by wading or by divers.

Fiberglass screens hold promise also as effective non-toxic controls of nuisance macrophyte growth. Further evaluation is recommended.

The placement of sheeting over the pond surface for short periods in the spring could be an effective device for small ponds in which *Potamogeton* is a nuisance. Dominance by other species after the sheeting is removed will probably occur but these could be less obnoxious species than *Potamogeton*. Further study is also required here.

3. The negative impact of fly ash on lake biota was very great in two reported field tests. Fish and zooplankton were killed, and in one case, completely eliminated. Elevated pH, low dissolved oxygen, and high concentrations of heavy metals were found. The material seems to be effective in laboratory tests in controlling P release, but critical field studies have not been completed. In view of the evidence indicating that fly ash will cause more problems than it solves, it is not recommended for lake restoration at this time.

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